270°C, 1 GHz oscillator-type active antenna

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Reported is the first demonstration of an active antenna operating at 1 GHz and at temperatures above 200°C. A Clapp oscillator integrated with a slot-ring antenna generated and transmitted a 1 GHz signal from 25 to 270°C. The oscillation frequency varied by less than 4% over the temperature range.

Introduction: There is an increasing demand for wireless sensors that operate in harsh environments or at high ambient temperatures. Potential applications are drill bit monitoring for oil exploration and mining, automotive engine sensors, and sensors that may be placed inside an aircraft engine to monitor combustion products, temperatures, and pressures throughout the duration of a flight [1–3]. Wide bandgap semiconductor transistors are especially suited for high temperature operation [4]. A 27.5 MHz sensor and data telemetry system operated through 400°C, with data transmission over a distance of 1 m [5]. This system used a packaged silicon carbide (SiC) transistor and hybrid fabrication techniques. For higher data rates, higher operation frequencies are required. A 1 GHz Clapp oscillator that operated through 200°C was reported [6], but it was not integrated with an antenna. This circuit used an unpackaged SiC transistor and hybrid integration techniques that relied on bond wires.

In this Letter, reported for the first time is the operation of an active antenna, consisting of the integration of a 1 GHz Clapp oscillator with a square slot ring antenna, at high temperatures. The system is fabricated on an alumina substrate with polymer-supported bridges for overpasses and ceramic chip capacitors. The SiC transistor is connected with wire bonds. The measured results show that hybrid circuit techniques can be used to build high temperature, active antennas at microwave frequencies.

Circuit design and fabrication: The 1 GHz Clapp oscillator uses the same design as in [6] and is shown in Fig. 1 with a Cree Inc. SiC metal semiconductor field effect transistor (MESFET), ceramic chip capacitors, and a thin-film inductor. The antenna is a square, slot ring antenna of 36.72 mm on a side that is optimised for impedance matching at 1 GHz when placed on a ceramic heater that has a dielectric constant of 4.5, which is required for high temperature characterisation. The balanced output of the oscillator is directly connected to the inner and outer edges of the slot antenna as shown in Fig. 2. To minimise the circuit size, the oscillator is placed inside the antenna and a bridge is used for connection to the outer edge of the slot. As the input impedance of the antenna does not vary with temperature [7], the impedance match between the antenna and the oscillator is less temperature-dependent compared to the ground/signal probe measurement of the oscillator reported in [6]. The circuit is fabricated on a 0.5 mm-thick alumina substrate with Cr and Au of thicknesses of 50 and 2500 nm, respectively. There is no metallisation on the backside of the substrate. Because wire bonds add substantial loss to the circuit and limit its high frequency, high temperature operation, their use was minimised in this layout. The wirebonds for the thin-film inductor and the connection between the oscillator and the outer edge of the antenna were replaced with 2.5 μm-thick bridges supported by a 2 μm-thick polymer. The only wirebonds used are for connection to the SiC MESFET. Bias for the transistor is provided by three DC needle probes. The drain bias is fed to the outer edge of the antenna, which is connected to the drain terminal through the overpass bridge. The source is tied to ground by a probe placed on the inner area of the antenna, and the gate bias is fed to the gate contact pad on the oscillator. These are identified in Fig. 2.

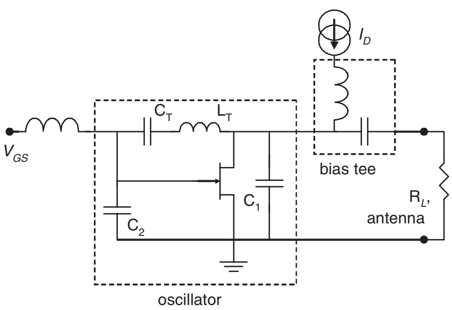

Fig. 1 *Schematic of active antenna*

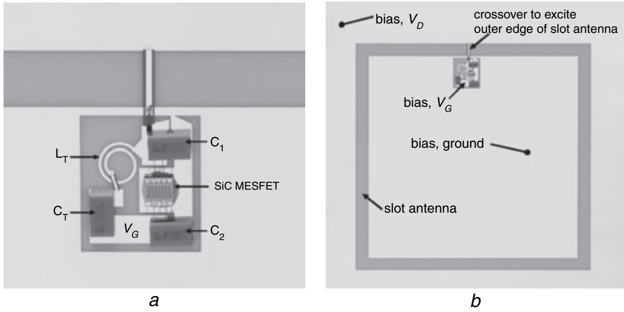

Fig. 2 *Hybrid implementation of Clapp oscillator and active antenna*

a Photograph of hybrid implementation of Clapp oscillator with chip capacitors, thin film inductor, polymer supported overpasses, and SiC MESFET
b Photograph of active antenna with circuit bias points labelled

Measured results: The active antenna is tested on a ceramic heater with a feedback loop to control the temperature [7]. A wideband horn antenna is placed 1 m above the active antenna, and a spectrum analyser measures the radiated signal at the horn. It is noted that the antenna radiates with a near omni-directional pattern with slightly more energy radiated into the ceramic heater owing to its higher relative permittivity. The drain voltage is maintained at 10 V and the gate bias is varied to maintain 130 mA drain current. The measurements begin with the ceramic heater temperature at 25°C and are incremented in 10 degree steps. The temperature is held constant for 10 min before the radiated signal is measured to assure that the circuit is at a uniform temperature.

Fig. 3 shows the measured signal at 270°C, and Fig. 4 shows the measured oscillation frequency and received power against the carrier temperature. It is seen that active antenna frequency decreases by less than 4% over the temperature range of 245°C. The power drops by 18 dB over the same range. The maximum temperature that the circuit operated is 270°C, after which the transconductance, g_m, of the transistor was no longer sufficient to offset the losses in the oscillator and the antenna [6].

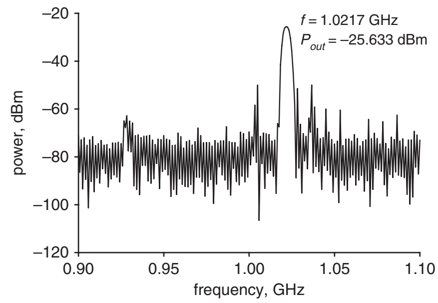

Fig. 3 *Measured spectrum of active antenna at 270°C carrier temperature*

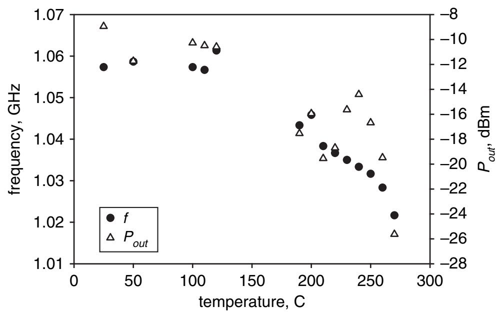

Fig. 4 *Measured received frequency and power against carrier temperature*

Conclusion: The high temperature demonstration of the active antenna verifies the ability of SiC-based hybrid circuits for harsh environment applications, and the use of wireless transmitters at microwave frequencies at temperatures greater than 250°C.

6 March 2009
doi: 10.1049/el.2009.0615

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